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Stream System Evaluation With Emphasis on Spawning Habitat for Salmonids

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This paper presents a comprehensive procedure for evaluating sedimentation impact on the streambed gravels used for spawning by salmonids. It establishes a relationship between embryo survival of incubating eggs and the geometric mean diameter of the substrate. It outlines simple procedures for estimating the overall composition of the gravel in spawning sites along stream reaches and provides the rationale for interpretation of these estimates in terms of overall embryo survival in a stream system.

INTRODUCTION

Water quality management programs conducted under state and federal legislation have identified nonpoint sources of pollution (NPS) as a significant obstacle to attaining the 1983 goal of water quality adequate for fish, wildlife and recreation [*Council on Environmental Quality*, 1978]. Stream sedimentation is one of the greatest NPS pollution problems, primarily because it results from activities as widespread as agriculture, silviculture, livestock grazing, and road construction. These types of intensive land uses can cause degradation of riffle habitats critical for salmonid fish reproduction and the production of invertebrate food organisms essential for juvenile fish [*Cedarholm and Lestelle*, 1974; *Iwamoto et al.*, 1978]. A study of spawning habitats could provide a relatively simple, sensitive, and meaningful indicator of the impacts of these land use practices.

This paper describes a procedure to help assess and monitor the effects of watershed management activities on salmonid spawning habitat. The monitoring program is designed to minimize cost and effort.

A UNIFYING SUBSTRATE STATISTIC

Fisheries researchers generally agree that excessive amounts of fine sediments in spawning gravel increase salmonid embryo and larval mortality by filling the spaces within the gravel [*Iwamoto et al.*, 1978]. This reduces substrate permeability and the rate of replacement of metabolite-laden water with oxygen-laden water during the incubation of embryos and larvae [*Cooper* 1965]. Also, the fine sediments may trap larvae trying to emerge [*Koski*, 1966; *Phillips et al.*, 1975]. Several measures of substrate 'fines' have been advocated, namely, fractions in percents less than 0.83 3.33, or 6.5 mm. There is no consensus on a universally acceptable definition of fine sediment [*Bjornn et al.*, 1974; *Koski*, 1966].

The main focus in fisheries literature concerning quality of spawning gravels is on the sand and silt fraction, as defined above. However, the natural spawning substrate contains a great amount of gravel and some cobble. These coarser fractions substantially influence permeability of the flow of water through the redd. Thus, a more balanced measure that realistically reflects this aspect of the spawning substrate is desirable.

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In an extensive analysis of the relationship between permeability and gravel composition, *Platts et al.* [1979] demonstrated that information on the entire textural composition of the gravel is necessary. They proposed the geometric mean particle diameter d_g as an appropriate statistic (several ways of calculating d_g are detailed by *Shirazi and Seim* [1979]) because (1) d_g is a convenient standard measure used in related fields such as hydrology, soil science, sedimentary petrology, and engineering, (2) d_g is a more complete description of total sediment composition than 'percent fines' and hence is a more appropriate measure of substrate habitat for spawning, (3) d_g relates to the permeability and porosity of sediments and to embryo survival at least as well as percent fines.

Shirazi and Seim [1979] presented an empirical relationship between geometric mean diameter of the spawning substrate and survival during embryo development to alevin emergence (Figure 1). To account for minor differences in egg size of species, d_g was divided by the egg diameter d_e for that species to produce a more strongly correlated relationship with survival (Figure 2). The strong correlation of d_g with embryo survival from diverse sources of data further supports the use of d_g advocated by *Platts et al.* [1979].

VISUAL ESTIMATION OF SUBSTRATE COMPOSITION

Because of the natural variability of stream gravel composition in time and space a rapid visual examination of gravel heterogeneity would be desirable to reduce sampling cost and effort. Field experiments were conducted in Oregon and Alaska to test our ability to estimate visually the relative differences in composition of two neighboring gravel patches [*Shirazi and Seim*, 1979]. At each location the spawning area was visually stratified into three groupings based on apparent composition of the surface gravels: coarse, fine, and intermediate. A single 12-in. (0.3 m) core sample was collected within each area and field-sieved. The mechanical analysis was subsequently used to test the accuracy of the visual estimates.

When mean particle diameters in bed material of neighboring patches differed by about 10%, using the visual procedure, we correctly identified the coarser material 87% of the time. When differences were about 20%, the visual estimation of relatively coarser material was correct 93% of the time.

With visual stratification of gravels, sample sizes may be adjusted to reflect the degree of variability within the sites of

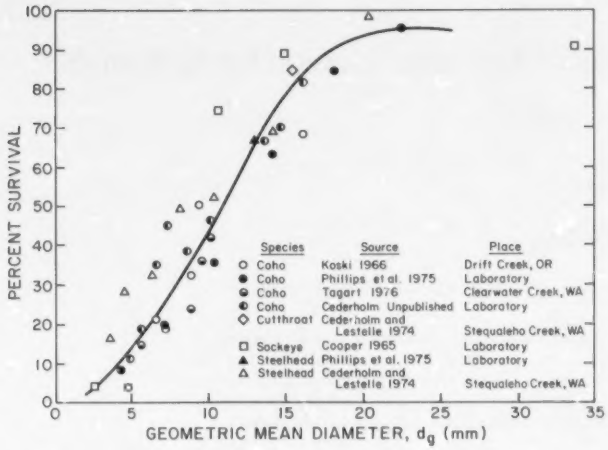
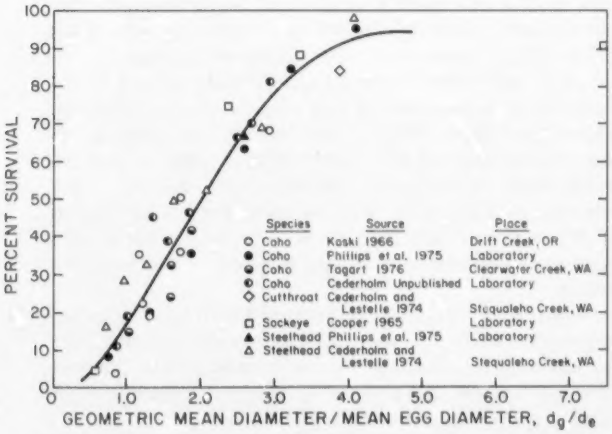

PERCENT SURVIVAL
GEOMETRIC MEAN DIAMETER, d_g (mm)
Species Source Place
Coho Koski 1966 Drift Creek, OR
Coho Phillips et al. 1975 Laboratory
Coho Tagart 1976 Clearwater Creek, WA
Coho Cederholm Unpublished Laboratory
Cutthroat Cederholm and Lestelle 1974 Stequaleho Creek, WA
Sockeye Cooper 1965 Laboratory
Steelhead Phillips et al. 1975 Laboratory
Steelhead Cederholm and Lestelle 1974 Stequaleho Creek, WA

Fig. 1. Relationship between percent embryo survival and the geometric mean diameter of the substrate.

interest. Fewer samples are needed in broad zones of homogenous material than in areas with a mosaic of different substrates. The number of samples to be taken along a stream reach consisting of tens to hundreds of sites is a function of variability in substrate composition among sites. The range of compositions along a stream reach is frequently reflected in typical sites. It is therefore adequate to examine a few of these sites in detail, taking one or more samples characterizing particle size distribution for perhaps three or more patches. The presence of similar patches within the remaining areas and the approximate areas of these patches should then be determined. Gravel patches selected as spawning sites should represent suitable characteristics of particle size range, water depth, and current velocity appropriate for the species of interest. Chinook salmon, *Oncorhyncus tshawytscha* select larger diameter spawning substrate than do, for example, resident trout species [*Platts et al.*, 1979].

Estimating Local and Streamwide Impacts

The ultimate goals of substrate monitoring are (1) to relate watershed processes and land use to channel substrate conditions and (2) to assess the possible impact of accelerated soil


PERCENT SURVIVAL
GEOMETRIC MEAN DIAMETER/MEAN EGG DIAMETER, d_g/d_e
Species Source Place
Coho Koski 1966 Drift Creek, OR
Coho Phillips et al. 1975 Laboratory
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Steelhead Phillips et al. 1975 Laboratory
Steelhead Cederholm and Lestelle 1974 Stequaleho Creek, WA

Fig. 2. Relationship between percent embryo survival and substrate composition in multiples of egg diameter.

TABLE 1. Stream Reach Evaluation of Spawning Gravel Composition in Canal Creek, Oregon, June 29, 1979

Geometric Mean Diameter d_g, mm	Average Area of Spawning Gravel, m^2/km	Cumulative Area Having Equal or Finer Composition Than Diameter Indicated, %
6	11	1
9	315	25
12	559	68
18	361	95
26	64	100

Total stream length surveyed was 2100 m, the approximate spawning area was 2750 m^2 (50% of reach), and the composition of pavement material was d_g = 86 mm.

erosion on spawning habitat. As an example of this approach, we analyzed substrate conditions in two Oregon coastal streams within the Siuslaw National Forest. Canal Creek was chosen to represent an impacted stream (its watershed has been extensively logged); Rock Creek was selected as the control, typifying a stream in an undisturbed area.

Our intent was not to actually assess land use impact on spawning substrate in Canal Creek by comparing conditions with Rock Creek, but to demonstrate the procedure, the effort required, and nature of results that can be obtained. An actual assessment requires 'before' and 'after' data and more comprehensive documentation of the rationale for selecting a given control.

In the study reported here, a 2-km reach of Canal Creek and a 1-km reach of Rock Creek were surveyed. On the average, the survey took 2 h/km. Two typical sites in Canal Creek and one in Rock Creek were also analyzed; four gravel samples were taken from each site. With two persons, sampling and field analysis of gravels required 4 hours for each site.

The stream substrate areas judged suitable for spawning are listed in Tables 1 and 2. We estimated that 50% of the reach in Canal Creek and 20% of the reach in Rock Creek were suitable for spawning. Furthermore, the total spawning areas that support better than 80% survival are 860 m^2/km for Rock Creek and 160 m^2/km for Canal Creek (Figure 3). In an actual assessment these results would indicate a substantial shift in both the potential quality and quantity of the substrate in Canal Creek, with consequent impacts on embryo survival and fish production.

Conclusion

The potential for widespread degradation of salmonid spawning habitat derives from increased human activities in

TABLE 2. Stream Reach Evaluation of Spawning Gravel Composition in Rock Creek, Oregon, June 6, 1980

Geometric Mean Diameter d_g, mm	Average Area of Spawning Gravel, m^2/km	Cumulative Area Having Equal or Finer Composition Than Diameter Indicated, %
9	15	2
17	55	8
30	180	28
37	262	57
50	400	100

Total stream length surveyed was 1000 m, the approximate spawning area was 912 m^2 (20% of reach), and the composition of pavement material was d_g = 80 mm.

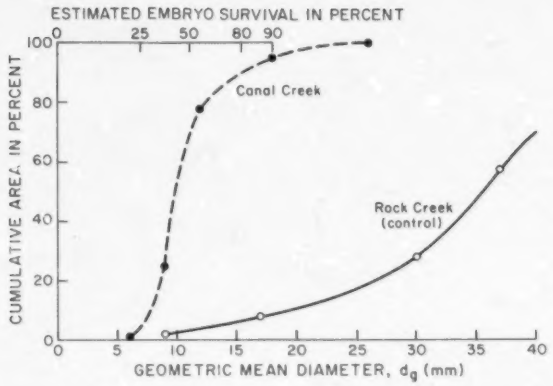

Fig. 3. Percent of cumulative spawning area having gravel composition equal to or less than mean diameter indicated for Canal Creek and Rock Creek. Corresponding embryo survivals are shown.

watersheds. The methodology presented here offers a practical and achievable means of obtaining the data base necessary for linking various watershed activities to their impact on the gravel environment.

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